The assembly history of the Milky Way satellites

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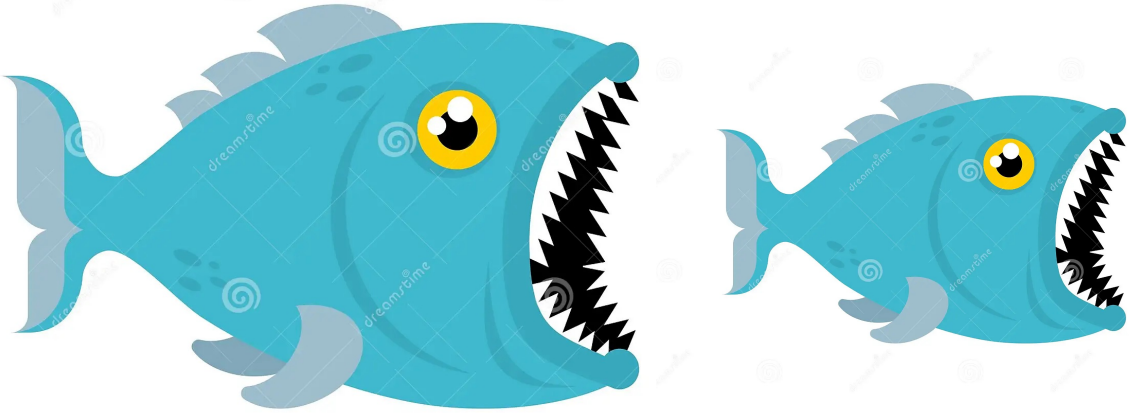
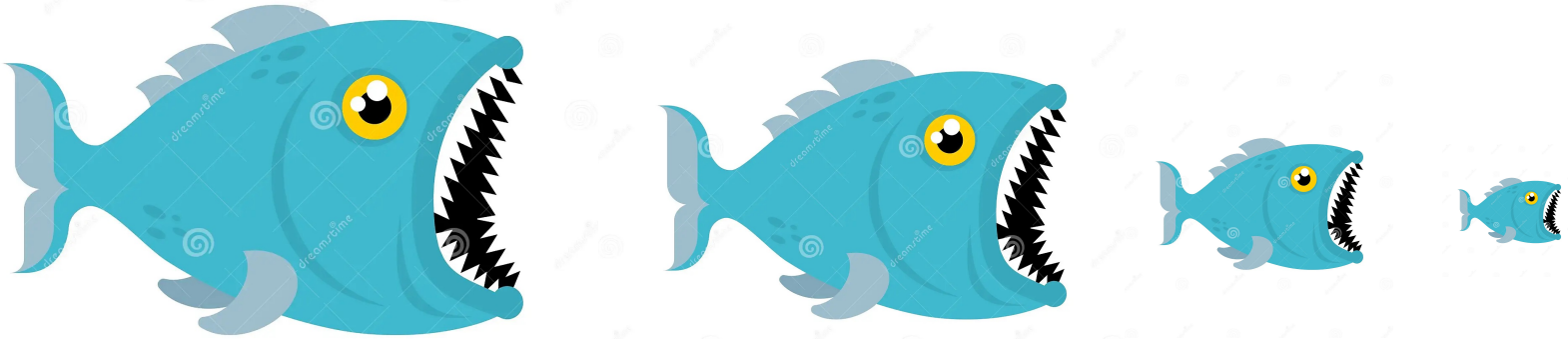
ΛCDM provides a framework to understand how galaxy form and evolve.

The galaxy formation proceeds hierarchically via a chain of mergers.

The most massive galaxies that we observe today in the Universe have built up to their current size hierarchically, by accreting smaller galaxies during past merging events.



The hierchical process should occur on all mass scales !!!

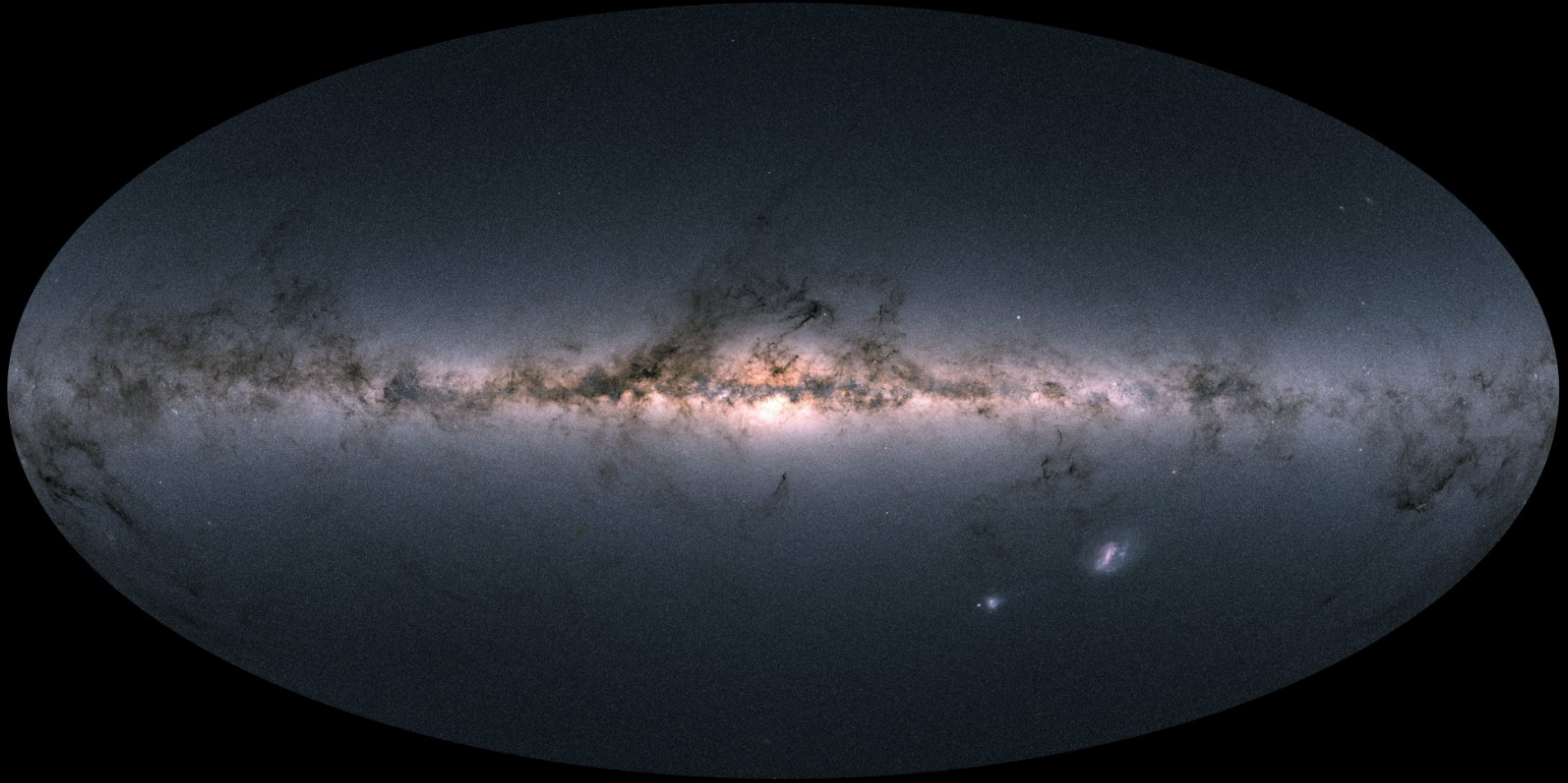


This implies that also the satellites of the Milky Way once had their own satellites

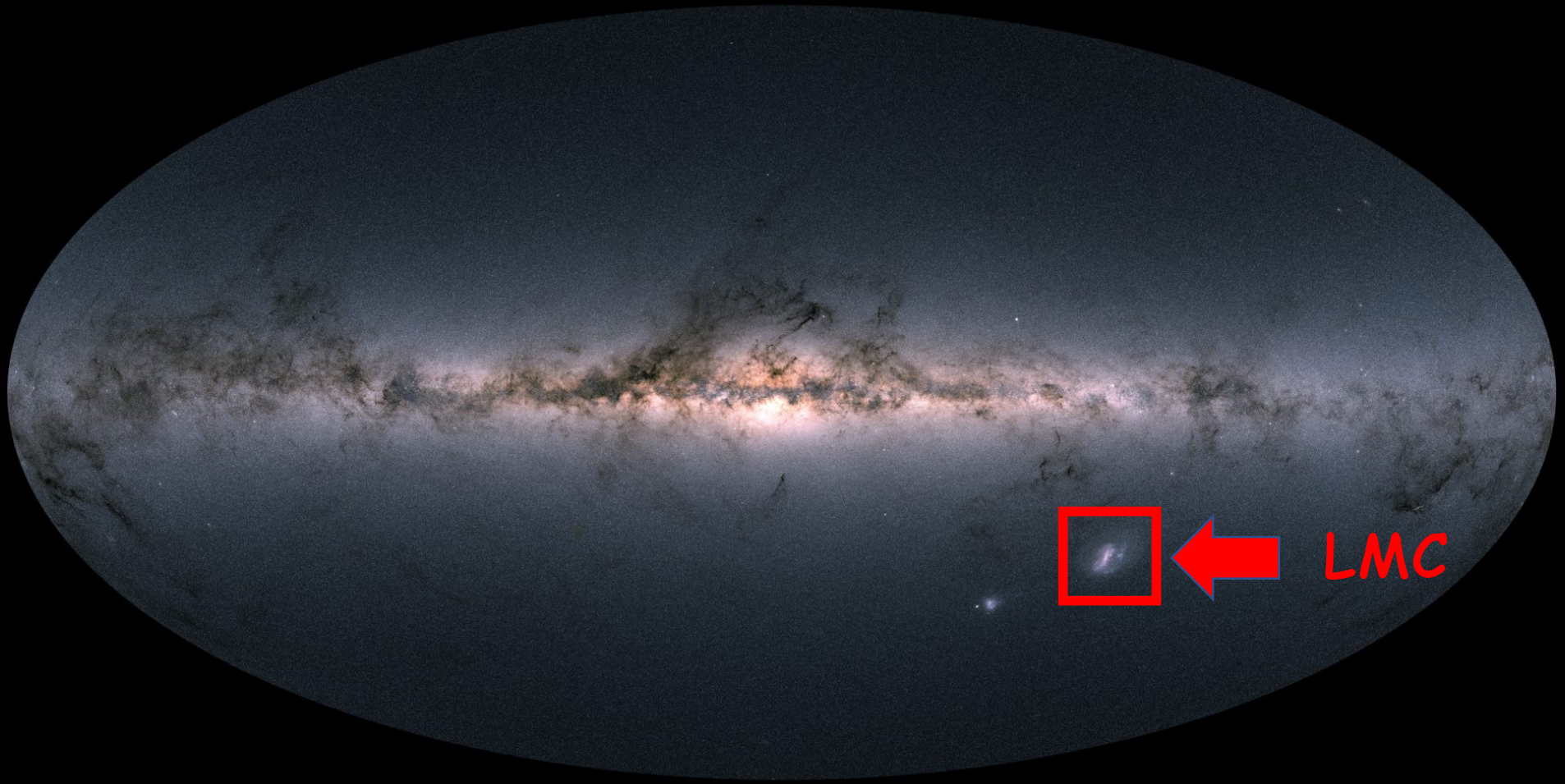
- Still-survived satellites of small systems are often too faint to be easily detected
- Other satellites of Milky Way satellites should be now completely dissolved into the parent galaxy after a merger event

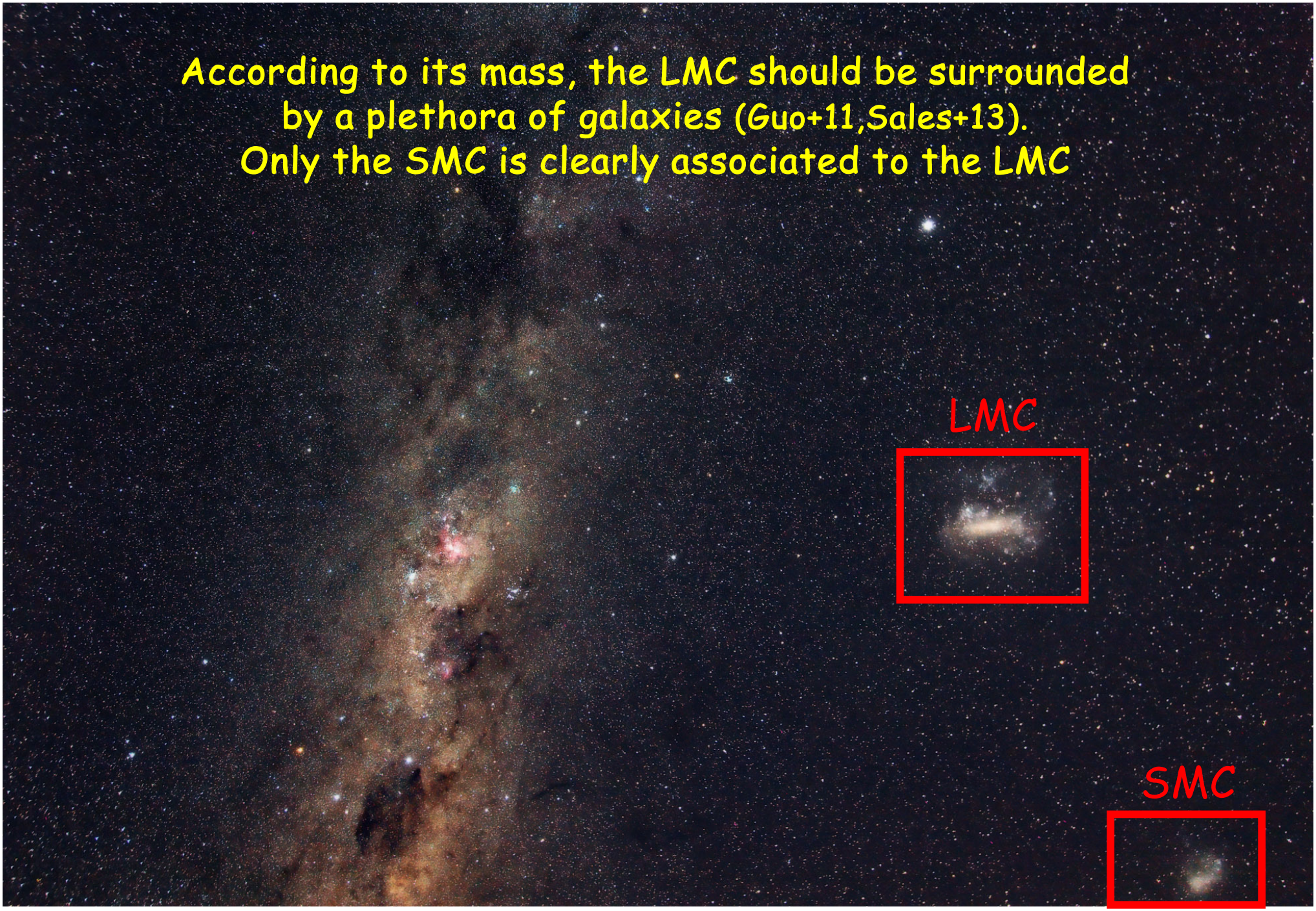
Where are these satellites today?

The Local Universe : a window into the process of hierchical mass assembly on all scales.



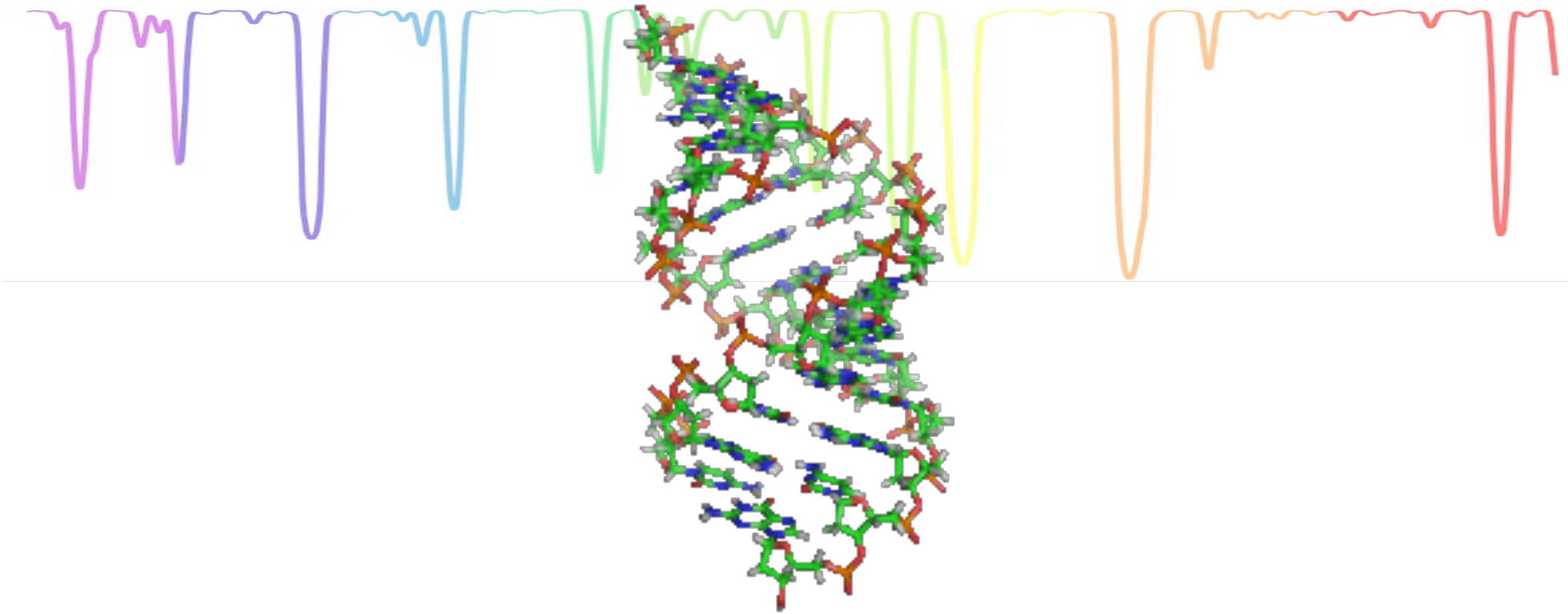
In the search of satellites of satellites
the LMC covers the role of the main actor




According to its mass, the LMC should be surrounded
by a plethora of galaxies (Guo+11,Sales+13).
Only the SMC is clearly associated to the LMC
LMC
SMC

Chemical composition = stellar DNA

The chemical composition is the only possibility to identify debris of dissolved galaxies now incorporated within the LMC.



LMC GCs dataset

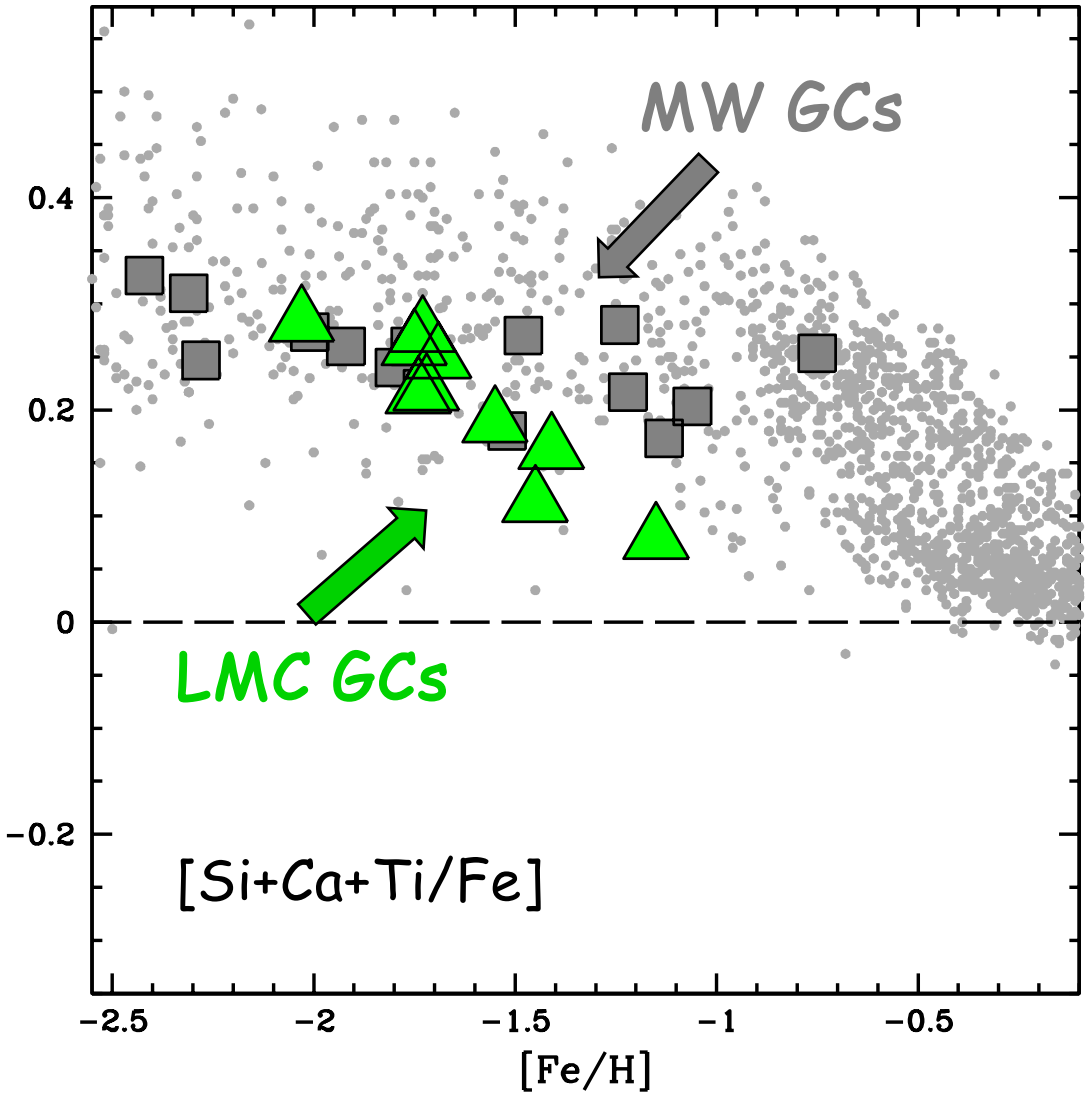
- 11 (out of 15) old LMC GCs
- 4 of them never analysed before
- UVES, FLAMES-UVES, MIKE

MW GCs dataset

- 15 MW GCs
- FLAMES-UVES

Both the datasets have been analysed
with the same assumptions
(strictly homogeneous analysis)

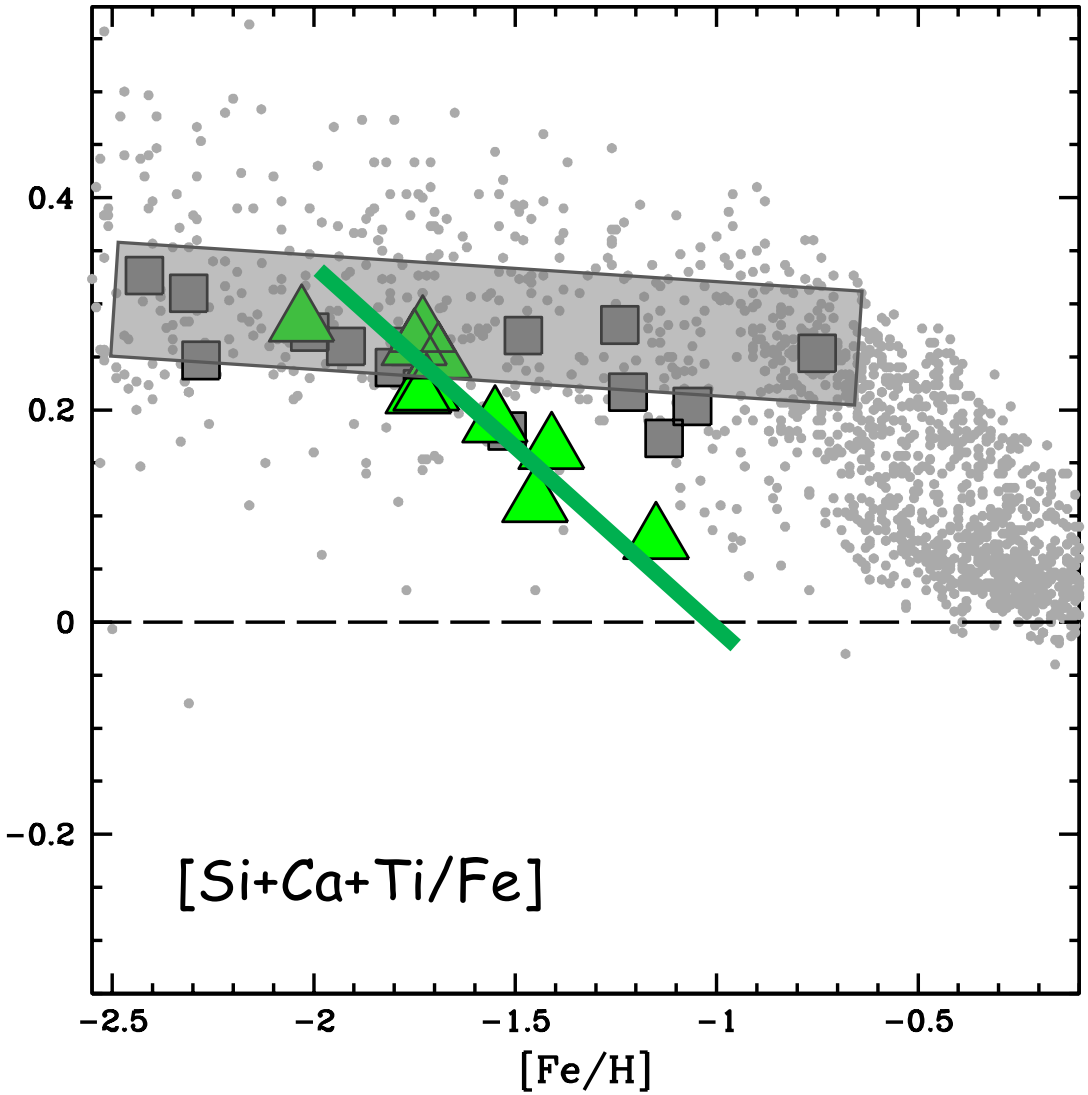
Comparison between LMC and MW GCs

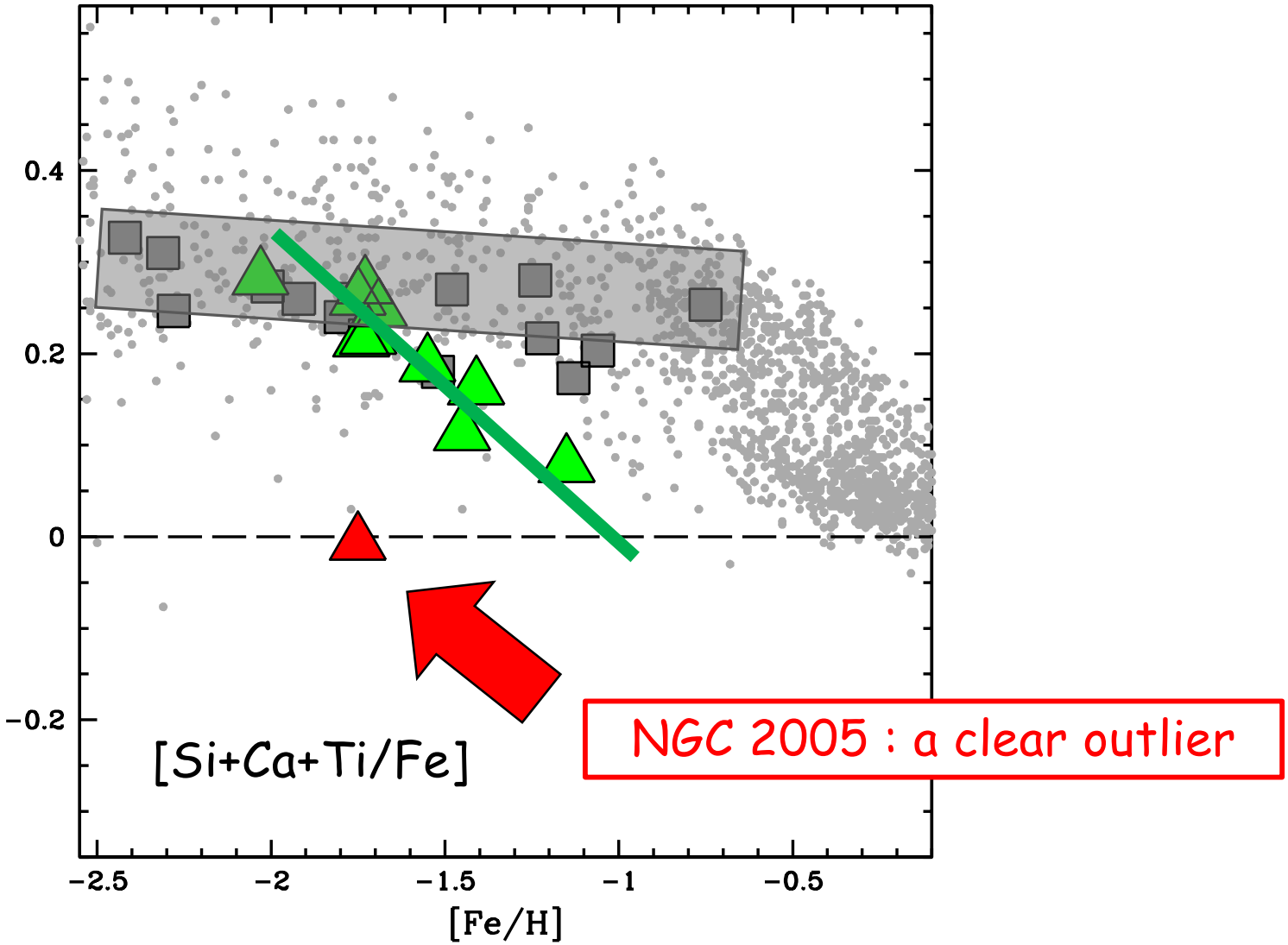


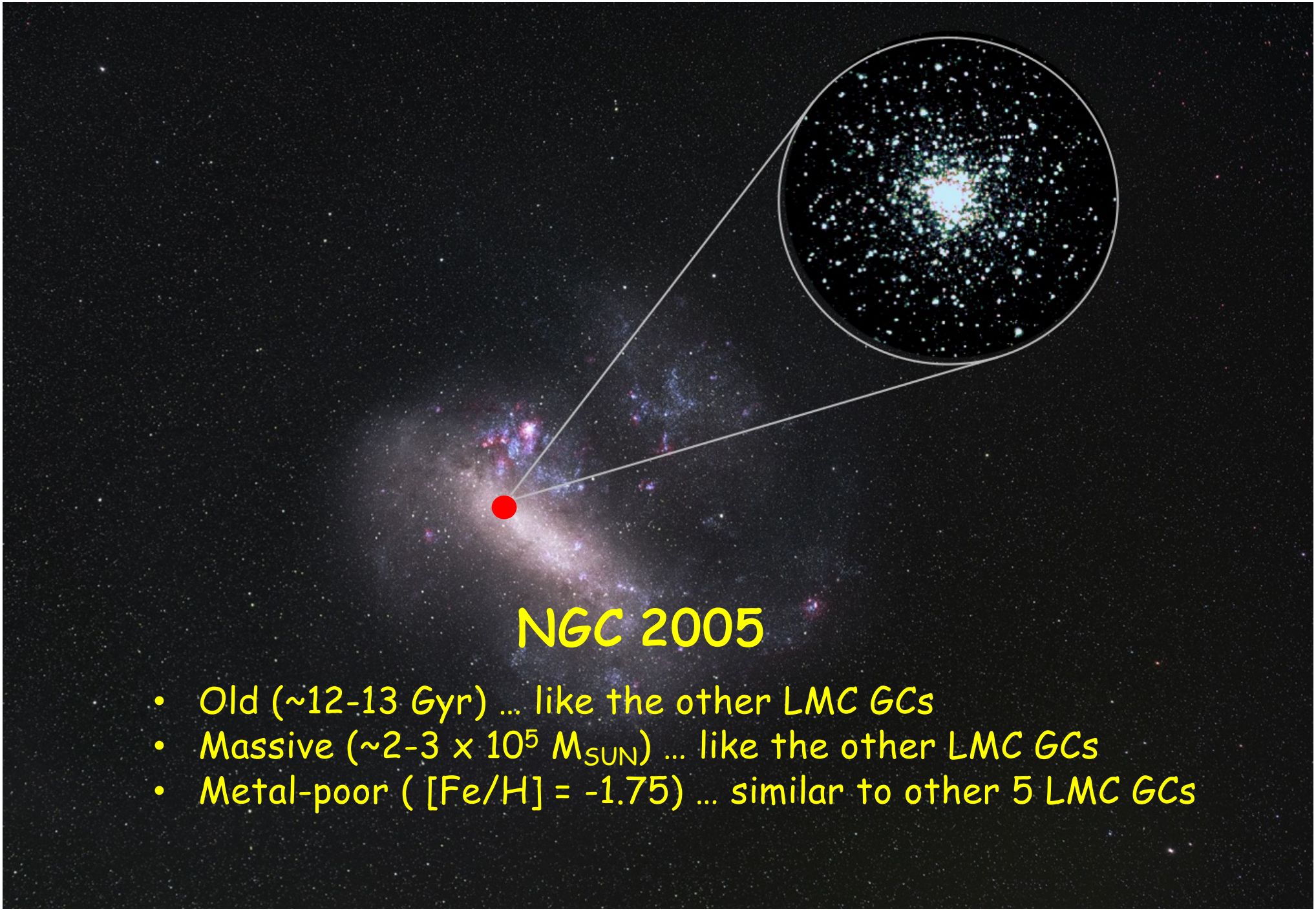
The LMC GCs draw well-defined sequences wrt MW GCs

This reflects the different chemical enrichment histories of the two galaxies

The *knee* in the LMC old population is at [Fe/H] < -1.8
(lower than that in the MW, [Fe/H] ~ -1)



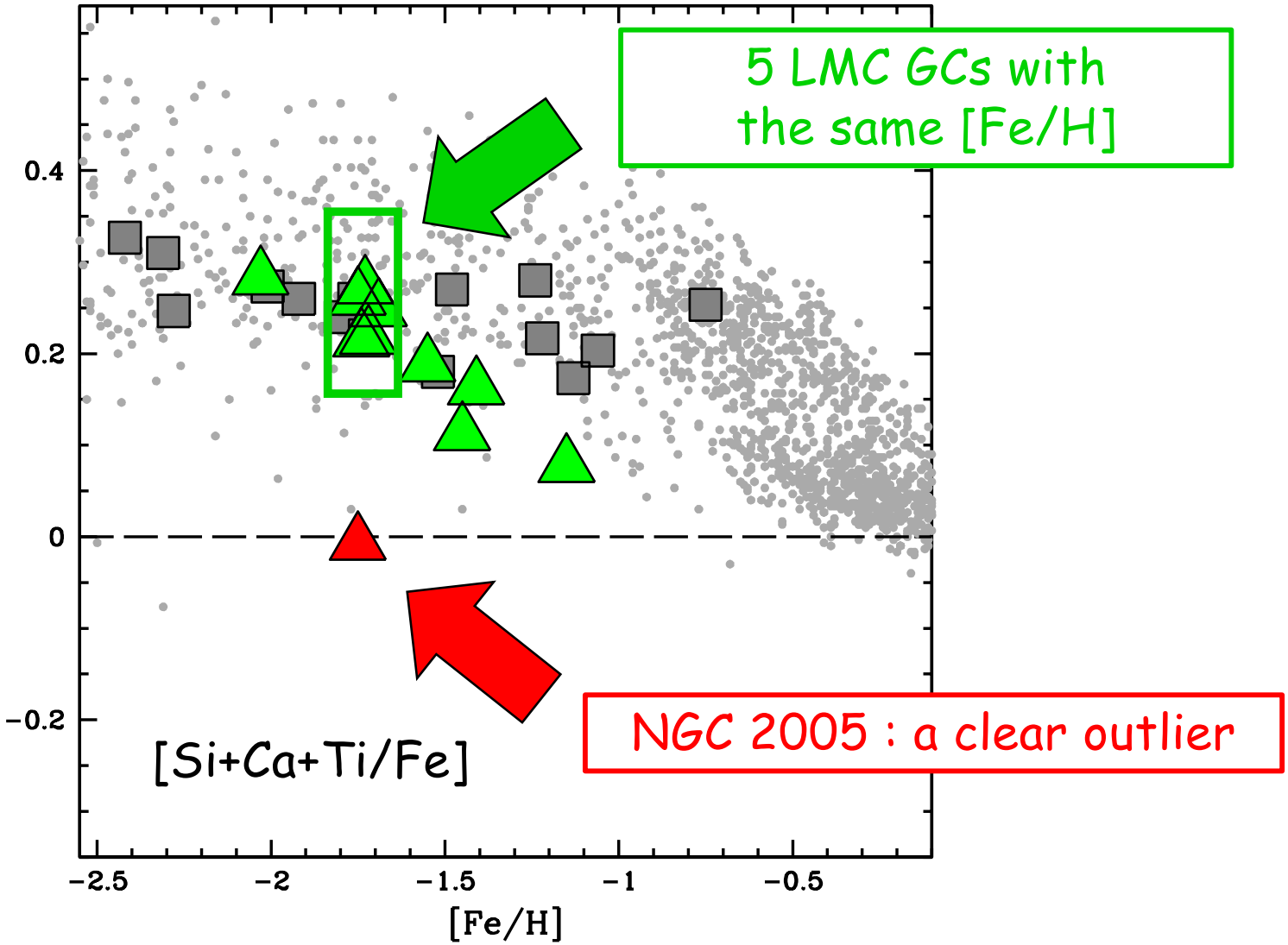

0.4
0.2
0
−0.2
−2.5
−2
−1.5
−1
−0.5
[Fe/H]
[Si+Ca+Ti/Fe]
NGC 2005 : a clear outlier



NGC 2005

- Old (~12-13 Gyr) … like the other LMC GCs
- Massive (~2-3 x 10^5 M_{SUN}) … like the other LMC GCs
- Metal-poor ([Fe/H] = -1.75) … similar to other 5 LMC GCs

We compare the chemical composition of NGC2005
with that of the 5 LMC GCs with similar [Fe/H]

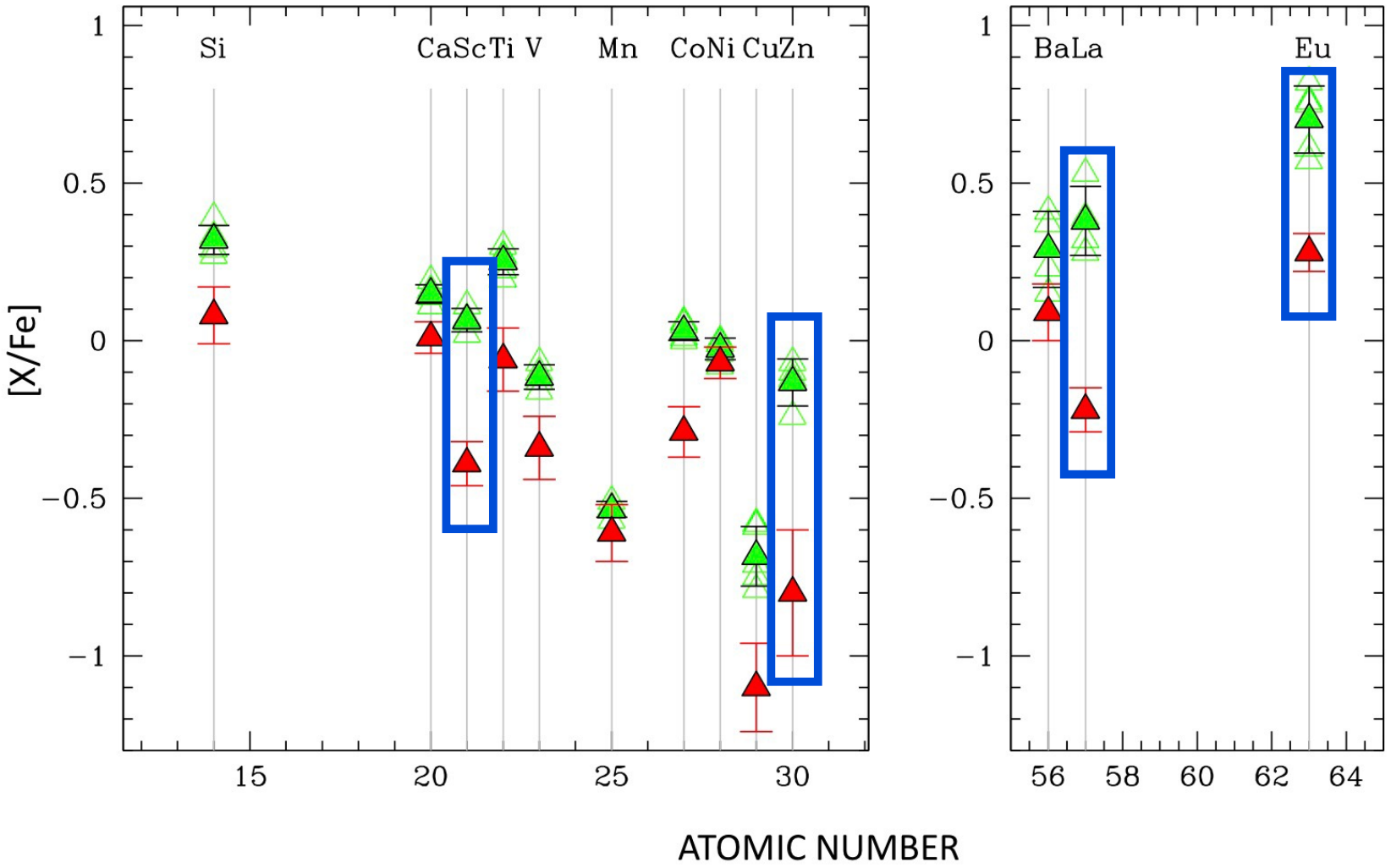


NGC 2005 systematically lower abundances wrt LMC GCs with similar [Fe/H] for all elements

NGC 2005

Average of 5 LMC GCs with similar [Fe/H]

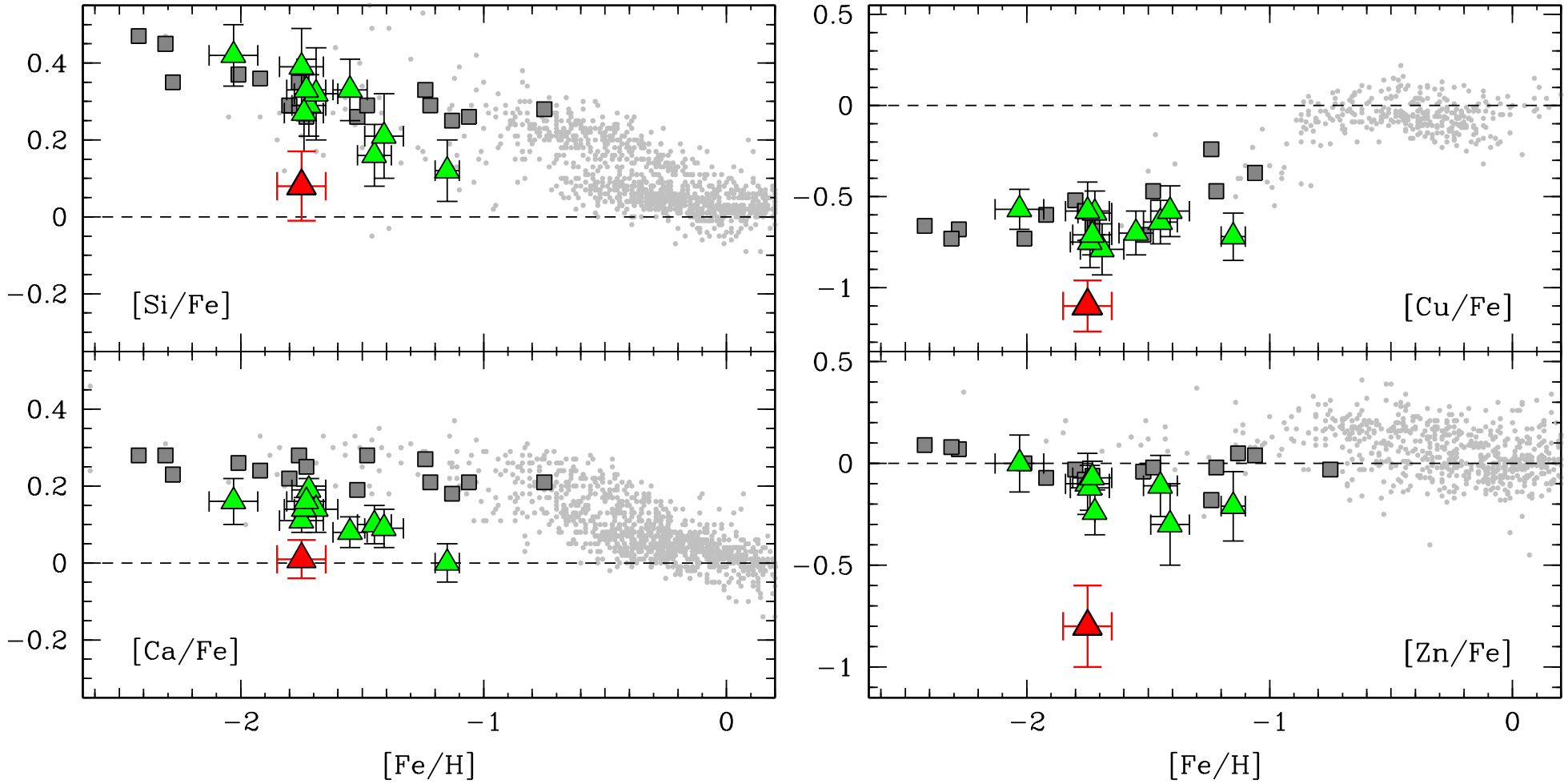
Mucciarelli+21



4 key-elements :

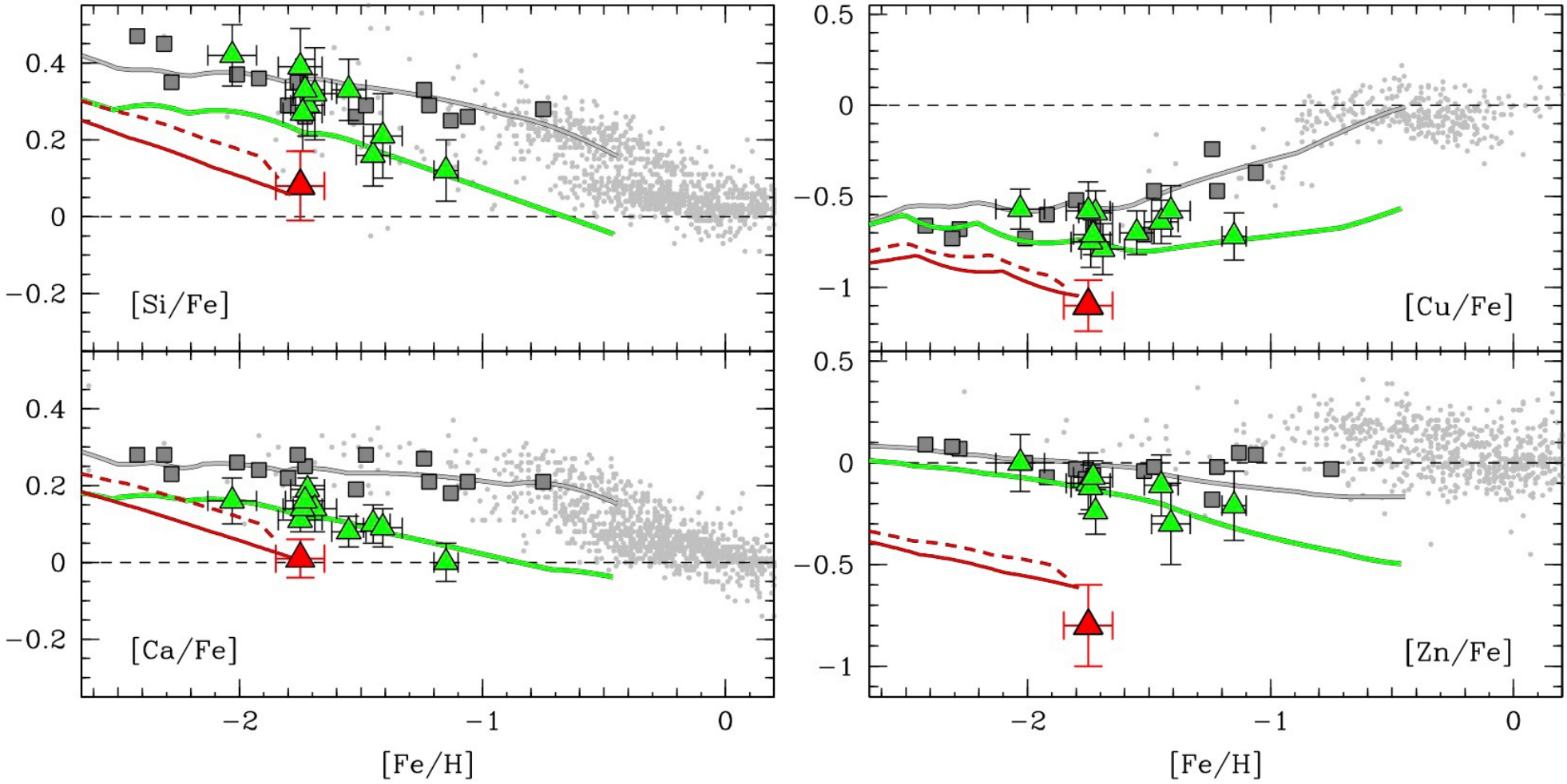
- **Si and Ca** (α-elements, massive stars + SNIa)
- **Cu** (s-process in massive stars)
- **Zn** (Hypernovae)

Mucciarelli+21



We calculated chemical evolution models for these key-elements assuming different star formation efficiencies.

Mucciarelli+21

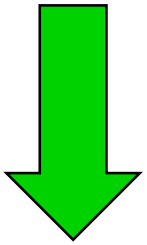


We reproduced the chemical abundances …

of the LMC GCs
with a star formation rate of ~1 M_{sun} / yr

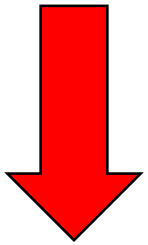
of NGC2005
with a star formation rate of ~ 10^{-4} M_{sun} / yr

LMC GCs with similar [Fe/H] : very similar abundances



Similar chemical evolutionary path:
they experienced a similar chemical enrichment history

NGC 2005 systematically lower abundance ratios



Different chemical evolutionary path:
NGC 2005 cannot have formed in the same environment of the other LMC GCs

nature astronomy

LETTERS

https://doi.org/10.1038/s41550-021-01493-y

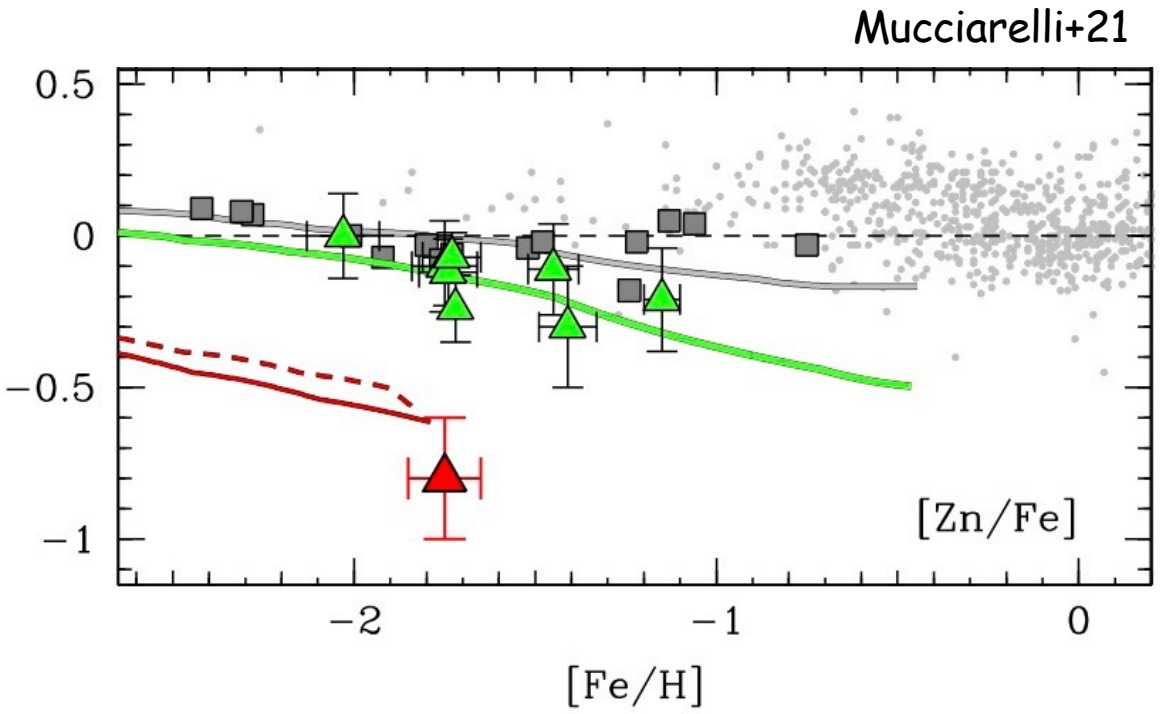
Check for updates

A relic from a past merger event in the Large Magellanic Cloud

A. Mucciarelli[1,2]✉, D. Massari[2,3], A. Minelli[1,2], D. Romano[2], M. Bellazzini[2], F. R. Ferraro[1,2], F. Matteucci[4,5,6] and L. Origlia[2]

According to the standard cosmological scenario, the large galaxies that we observe today have reached their current mass via mergers with smaller galaxy satellites[1]. This hierarchical process is expected to take place on smaller scales for the satellites themselves, which should build up from the accretion of smaller building blocks[2]. The best chance we have to test this prediction is by looking at the most massive satellite of the Milky Way: the Large Magellanic Cloud (LMC). Smaller galaxies have been revealed to orbit around the LMC[3,4], but so far the only evidence for mutual interactions is related to the orbital interplay with the nearby Small Magellanic Cloud, which is the most massive LMC satellite. In this work, we report the likely discovery of a past merger event that the LMC experienced with a galaxy with a low star formation efficiency and likely a stellar mass similar to those of dwarf spheroidal galaxies. This former LMC satellite has now completely dissolved, depositing the old globular cluster NGC 2005 as part of its debris. This globular cluster, the only surviving witness of this ancient merger event, is recognizable through its peculiar chemical composition. This discovery is observational evidence that the process of hierarchical assembly has worked also in shaping our closest satellites.

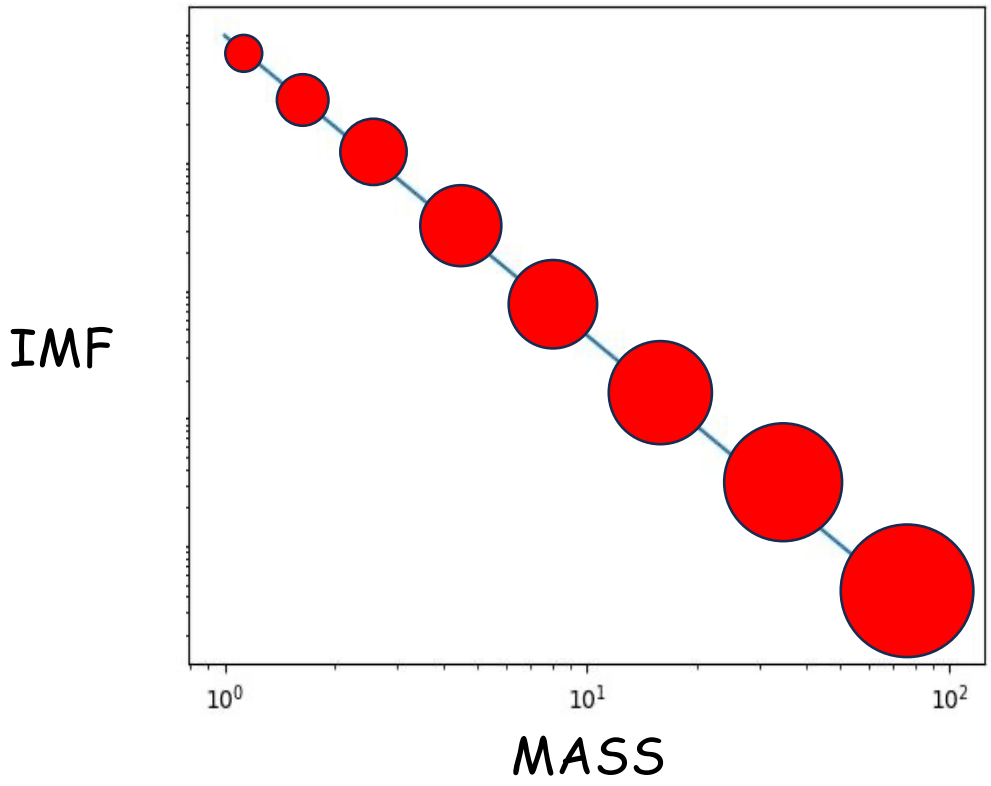
A NEW ACTOR ON THE STAGE … ZINC



Zinc is produced almost totally by hypernovae

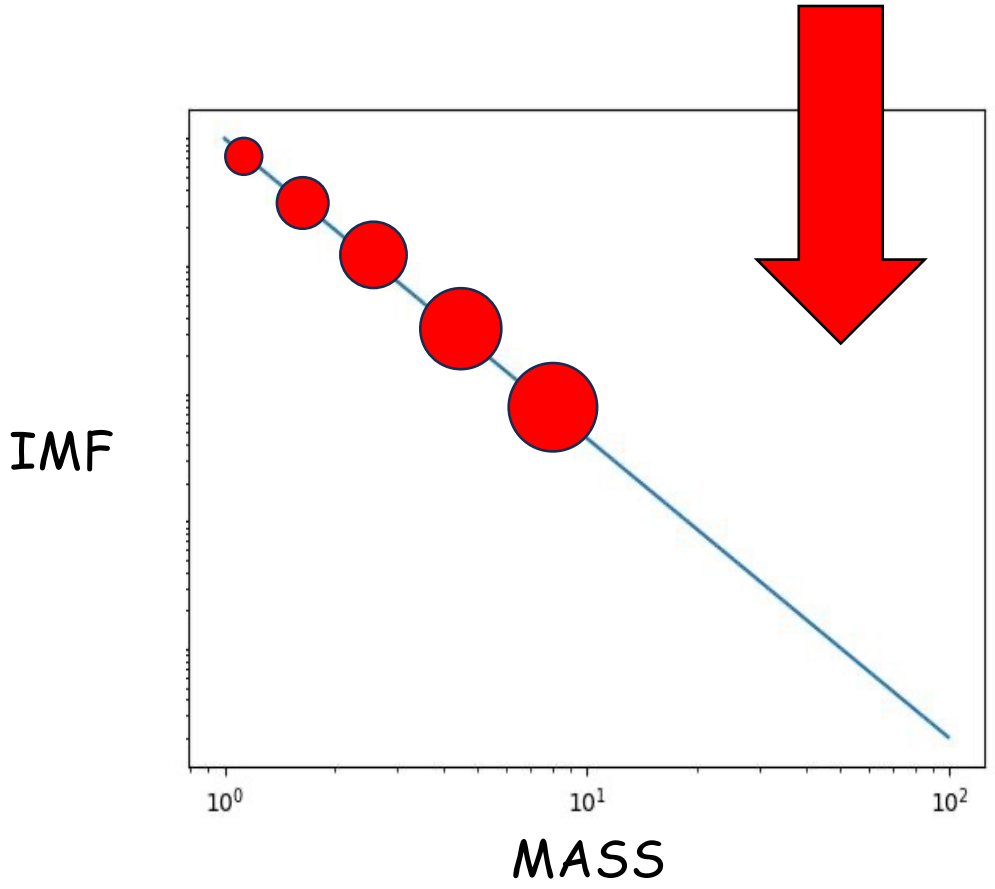
- Significantly more energetic than standard CC-SNe
- Associated to stars with initial stellar masses larger than 30-35 Msun (i.e. Kobayashi+06, Nomoto+13)

Small mass galaxies with low star formation rates can have lower upper mass limits for the IMF.



Small mass galaxies with low star formation rates can have lower upper mass limits for the IMF.

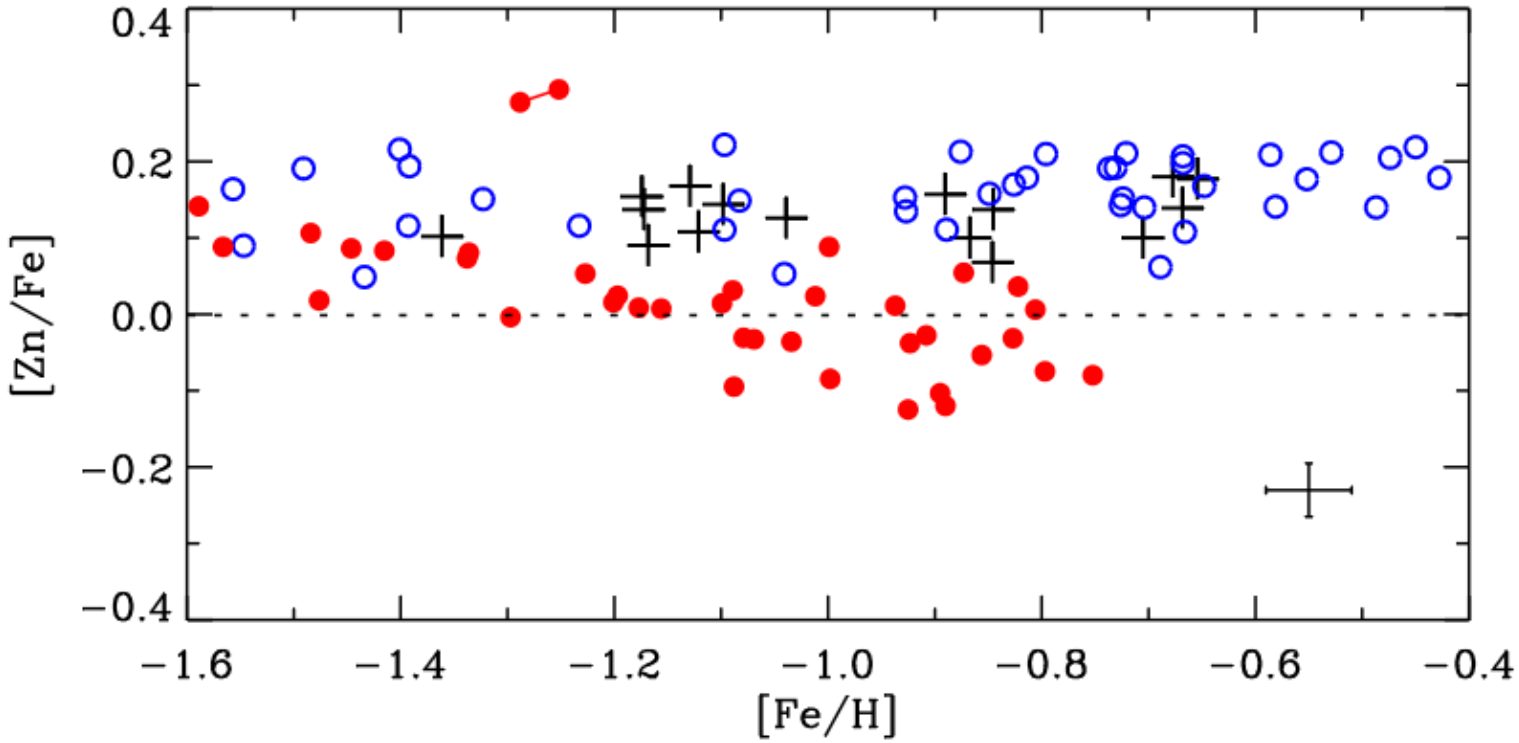
The contribution of high-mass stars to the chemical enrichment can be reduced or suppressed.



In galaxies with low star formation rates:

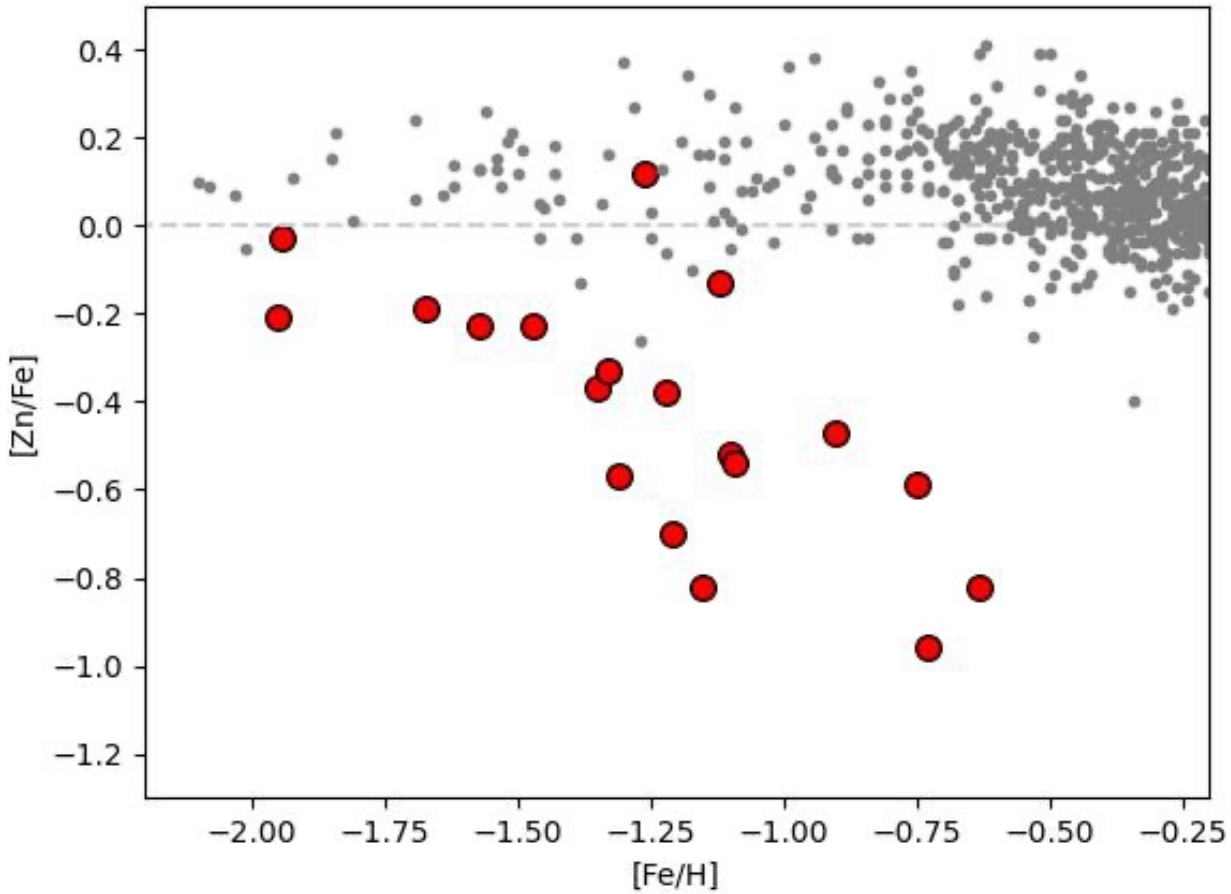
- the contribution of hypernovae is reduced or suppressed
- [Zn/Fe] is lower than the Milky Way

Nissen & Schuster 2011



Other galaxies in the Local Group … Sagittarius dwarf spheroidal galaxy

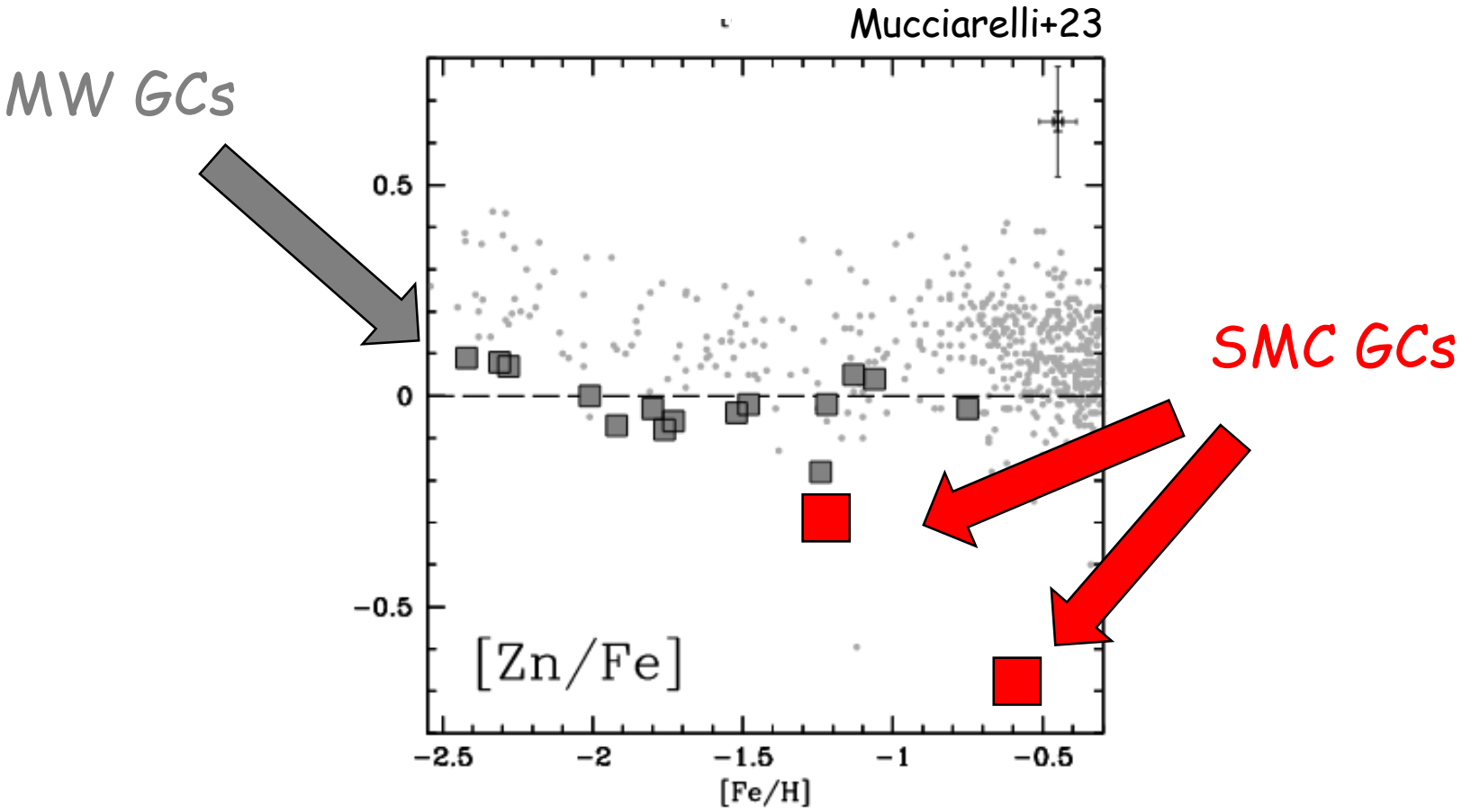
Liberatori, Mucciarelli et al. (in prep.)



See also the poster by Luca Sbordone

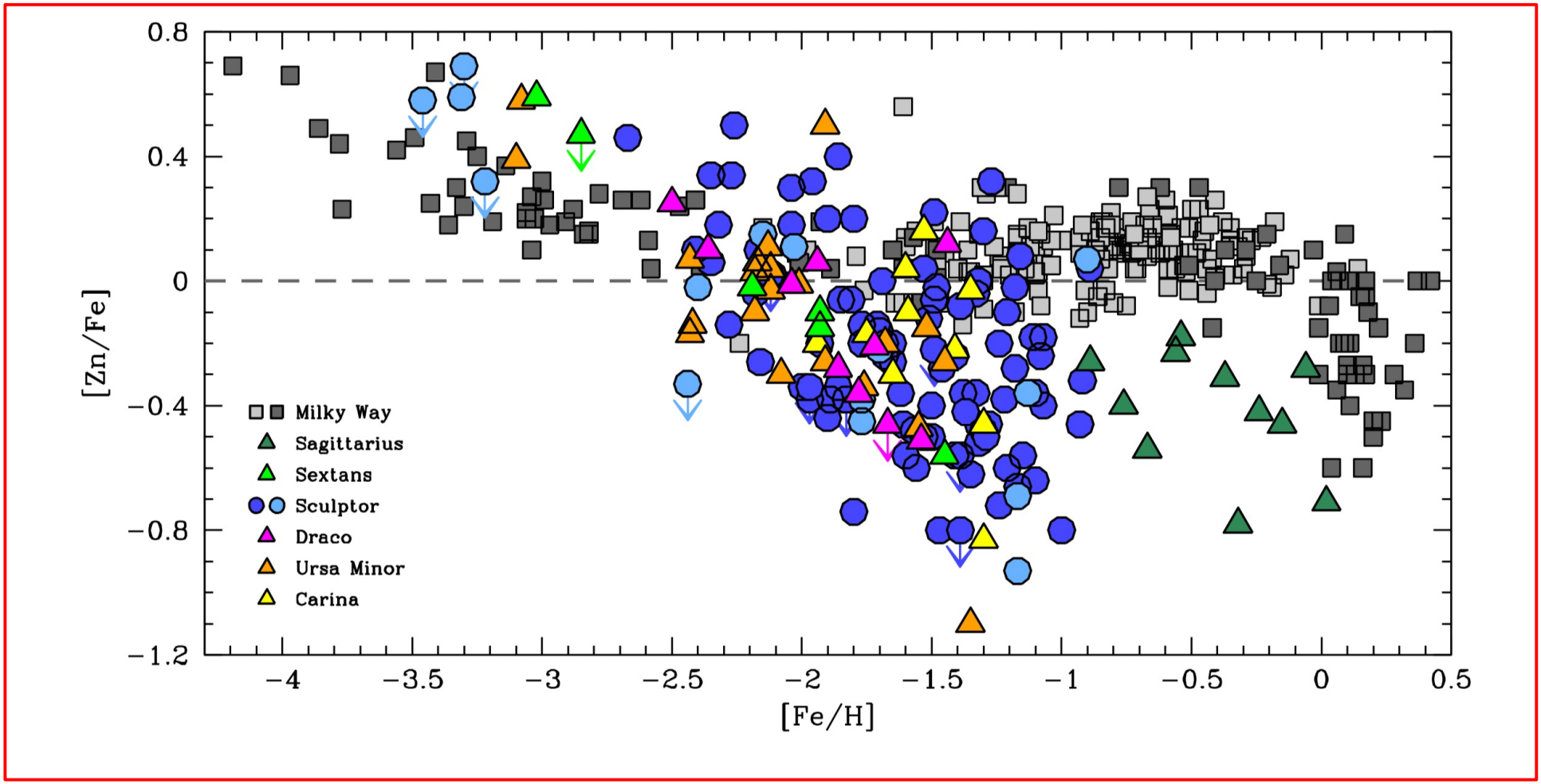
Other galaxies in the Local Group … the SMC

[Zn/Fe] available only for two SMC globular clusters but they have [Zn/Fe] lower than the Milky Way



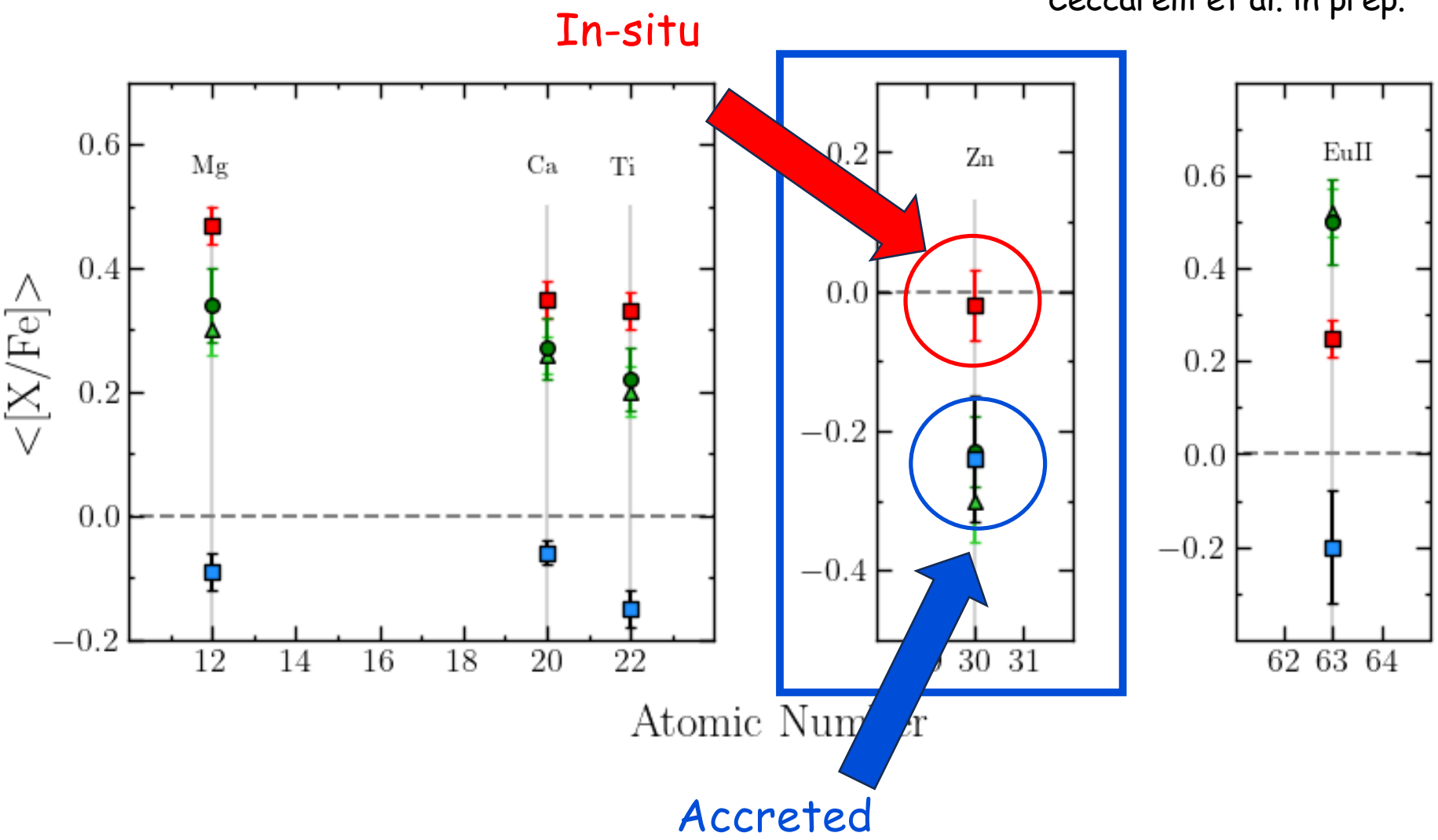
Other galaxies in the Local Group … Sculptor dwarf spheroidal galaxy

Skuladottir+17



…but also accreted GCs (GSE + Helmi streams) … see Ceccarelli's talk

Ceccarelli et al. in prep.



SOME TAKE-HOME MESSAGES …

The lesson from LMC old clusters

The process of hierarchical assembly has worked also in the LMC.

The chemical tagging can be used to reconstruct the assembly history also in Milky Way's satellites.

The lesson from Zinc

[Zn/Fe] is depleted in systems with a lower SFR wrt Milky Way (LMC, SMC, Sagittarius, Sculptor).

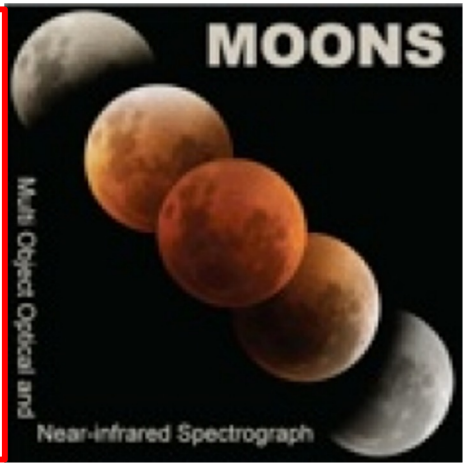
[Zn/Fe] is a powerful diagnostic for accreted stars.

NEXT STEPS …

Other accreted LMC clusters?
40 hours of VLT time (UVES+FLAMES) to study other three old LMC GCs
… work in progess !!!

MOONS@VLT (1000 fibers over 500 arcmin^2)

MOONS GTO
30 nights over 5 years dedicated to Galactic satellites (LMC,SMC,Sgr), see Gonzalez, Mucciarelli et al. 2020



REMEMBER OF ZINC !!!!!


The End